Poky Linux with IMGUI Demo on *Raspberry* π

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1 introduction

These interactive instructions[5] follow the configuration and build of a Linux-based *operating system* (OS) for *Raspberry* π[6]. The goal of the project is a compact and deterministic OS with a simple *graphical user interface* (GUI). Standard *command-line interface* (CLI) tools ensure device remote access and control. The build is done with *Yocto*[8].

There are several steps organized in corresponding sections as follows. Read in Section 2 how to fetch *metadata*. Section 3 shows how to configure the OS build. In Section 4 learn how to build the OS *image* and see how to copy *image* to *SD* card in Section 5. Section 6 is dedicated to post-install issues like the configuration of the WiFi interface from the command line.

2 metadata

In current context, *metadata* is a set of *instructions* to build *targets*. The build configuration is managed via files with extension `conf`. They define configuration variables to control the build process.

2.1 structure

Basic concepts needed to understand *metadata* structure follow.

2.1.1 recipes

The *instructions* are organized as *recipes* in files with the `bb` extension. There are also files with the `bbappend` extension designed to modify *recipes* and *bitbake classes* with the suffix `bbclass` for instructions shared between *recipes*. See a full list of *metadata* file types in Table 2.

2.1.2 targets

The target may be a *software* (SW) package or group of packages. The target may also be a complete OS *image*.

2.1.3 layers

Metadata is organized in *layers*. Layers logically separate information of a project. Table 1 presents *OpenEmbedded*[3] *metadata* layer types.

The complete list of *github* SW *metadata* repositories used in this project includes *Yocto* layers, the *Raspberry* π *board support package* (BSP) layer, a SW layer with custom recipes including target and distribution definitions, and the build configuration itself.

layer type	contents
base	base *metadata* for the build
machine aka BSP	*hardware* (HW) support
distribution	policy configuration
SW	additional SW
miscellaneous	do not fall in upper categories

Table 1: *metadata* layer types as defined by *OpenEmbedded*[3]

file type	extension	purpose
recipe	`bb`	SW build instructions
recipe	`bbappend`	SW recipe modification
class	`bbclass`	shared instructions
config	`conf`	build directives
config	`inc`	shared build directives

Table 2: *metadata* file types

In short, users fetch *metadata* in contrast to the *real* data fetched later during the OS build. See Section 4 for details. It means that users decide where to store fetched *metadata*. It is nice to have all layer sub-directories in one system location. In these instructions it is referred as <META-DIR>. The second directory to create is the <BUILD-DIR>. This is where the build and the build configuration live. I suggest that <BUILD-DIR> is not inside <META-DIR> to not mix *data* and *metadata*.

2.2 meta-thc

Following the *OpenEmbedded metadata* classification, `meta-thc` is a SW layer as there are SW recipes. On the other hand, it is a distribution layer because it defines a new distribution based on *poky*.

See <META-DIR>`/thc/meta-thc/conf/distro/thc.conf`. In addition, there is an *image* recipe to build a target in <META-DIR>`/thc/meta-thc/recipes-core/images/core-image-thc.bb`.

This allows for an effective isolation of machine, distribution and image features of the OS. The layer includes also shell scripts to clone *metadata* and to export the OS *image* on *SD*-card. These may be found in <META-DIR>`/thc/meta-thc/bin`. Learn more in following sections. See next the contents of `meta-thc`. The system location of the layer is <META-DIR>`/thc/meta-thc` by default.

```
.
    bin
        burn
        metafetch
        yoctoinit
    classes
        thclass.bbclass
        thconf.bbclass
    conf
        distro
            thc.conf
        layer.conf
    recipes-core
        dhcpcd
            dhcpcd_%.bbappend
        images
            core-image-thc.bb
        init-ifupdown
            init-ifupdown_%.bbappend
        thcp
            thcp
                rpip
                toprc
                wifini.sh
            thcp_0.0.1.bb
            thcp_0.1.0.bb
            thcp_1.0.0.bb
    recipes-sw
        glfw
            glfw_3.3.3.bb
            glfw_3.3.8.bb
        imgui
            imgui
                imgui.ini
            imgui_0.0.1.bb
            imgui_0.1.0.bb
            imgui_1.0.0.bb
    CODE_OF_CONDUCT.md
    CONTRIBUTING.md
    LICENSE
    README
```

```
15 directories, 26 files
```

2.3 automation

There is a shell script to clone all *metadata* from public *github* repositories. It may serve people to build their own OS for *Raspberry* π. The script performs *metadata* fetch, the *bitbake* initialisation and a simple *metadata* verification.

```
#!/bin/sh
# name:     metafetch
# purpose:  clone rpi metadata
# code:     kaloyan@triplehelix-consulting.com

FETCHER=https://github.com/
GITFETCHER=git@github.com:
BRANCH=kirkstone

LONGSFX=$(head -c 1000 /dev/random | tr -dc 'a-z')
SFX=$(expr "$LONGSFX" : ".*\(.\{3\}\)")
unset LONGSFX

DEFMETADIR=$HOME/yocto/$SFX/metadata
DEFBUILDIR=$HOME/yocto/$SFX/rpi4

TARGET=core-image-thc

XNAME=$(basename $0)

say() { printf ":: $XNAME :: $*\n"; }
die() { say $* && exit 0 || kill $$; }
use() {    # print options and quit

    printf "
usage:
\t $XNAME <options>
    option          \t purpose                  \t default
    -h              \t print this               \t usage
    -d              \t dry run                  \t wet run
    -g              \t switch to git protocol   \t https protocol
    -r <branch>     \t branch                   \t $BRANCH
    -m <metadir>    \t metadata directory       \t $DEFMETADIR
    -b <buildir>    \t build directory          \t $DEFBUILDIR

"
    die
}

confirm() {    # get confirmation or quit

    read -p "please confirm (y/n) " choix
    [ "$choix" == "y" ] && say confirmed || die
}
```

```bash
[ "$SFX" ] || die try again

while getopts ":m:b:r:hgd" option; do    # parce command-line options

    case $option in

        m ) METADIR=$OPTARG;;
        b ) BUILDIR=$OPTARG;;
        r ) BRANCH=$OPTARG;;
        g ) FETCHER=$GITFETCHER;;
        d ) DRYRUN=yes;;
        h ) use;;
        * ) use;;
    esac
done

# check system path
[ "$METADIR" ] || METADIR=$DEFMETADIR
[ "$BUILDIR" ] || BUILDIR=$DEFBUILDIR
[ -d $METADIR ] || mkdir -p $METADIR || die $? cannot create $METADIR
[ -d $BUILDIR ] || mkdir -p $BUILDIR || die $? cannot create $BUILDIR
METADIR=$(realpath $METADIR) && say "metadata:\t $METADIR" || die $? cannot find
   $METADIR
BUILDIR=$(realpath $BUILDIR) && say "build:\t $BUILDIR" || die $? cannot find
   $BUILDIR
say "branch:\t $BRANCH"
say "protocol:\t $FETCHER"

declare -A REPO
REPO=(    # associative git repository array
    [yoctoproject/poky.git]=$METADIR/poky
    [openembedded/meta-openembedded.git]=$METADIR/oe
    [agherzan/meta-raspberrypi]=$METADIR/rpi/meta-raspberrypi
    [kaloyanski/meta-thc.git]=$METADIR/thc/meta-thc
    [TripleHelixConsulting/rpiconf.git]=$BUILDIR/conf
)

[ "$DRYRUN" ] || confirm

for repo in ${!REPO[@]}; do    # clone repositories

    command="git clone -b $BRANCH $FETCHER$repo ${REPO[$repo]}"
    say $command
    [ "$DRYRUN" ] || $command
done

[ "$DRYRUN" ] && die

# adjust bibtbake layer configuration
sed -i s#/home/yocto/layer#$METADIR#g $BUILDIR/conf/bblayers.conf || die sed $?

# bitbake environment initialisation
OEINIT=oe-init-build-env
cd $METADIR/poky && pwd || die $? cannot find $METADIR/poky
[ -f $OEINIT ] && . ./$OEINIT $BUILDIR || die $? cannot find $OEINIT

bitbake-layers show-layers

echo && say "how to start a new build"
```

```
printf "
cd $METADIR/poky
. ./$OEINIT $BUILDIR
bitbake $TARGET

"
```

You may download `metafetch` here. Note the associative array `REPO`. It defines the remote and local system path of repositories. The script is designed in a way that after a successful run one may start a build with *bitbake*. Do not forget to grant permissions to make script executable. It takes <META-DIR> and <BUILD-DIR> names from the command-line. You may use next examples to run `metafetch`. Running the script without command-line options like the first example results in some default configuration. You may want to specify custom directories like the second example. Otherwise the script will use default values. The default *github* protocol is *https* but I recommend using *git* because it is an order of magnitude faster. You may need to export one *secure shell* (SSH) public key to your `github` account. Use the command-line option $-g$ to switch protocol. The default *git* branch is *kirkstone*. Use `-h` to see all CLI options.

```
chmod +x metafetch

./metafetch
./metafetch -m <META-DIR> -b <BUILD-DIR>
./metafetch -g
```

3 configuration

Build configuration is in <BUILD-DIR>`/conf`, check files `local.conf` and `bblayers.conf`. *Yocto* layers are specified in `bblayers.conf`. The build directives are in `local.conf`. Variables in this file control the build. Sometimes I call these *directives* to avoid repetitions. To not mix them, I have isolated target HW specific directives. Two possible targets are defined in <BUILD-DIR>`/conf/raspberrypi4-64.inc` and <BUILD-DIR>`/conf/qemuarm64.inc`. The *host* configuration is optional. See the bottom lines in <BUILD-DIR>`/conf/local.conf` for details. Note the difference between the optional `include` and not optional `require`. The latter will interrupt the build configuration if the corresponding file does not exist.

3.1 directives

Directives control the build. It is not always easy to understand their meaning and their relations. For example, some directives change values of other directives. What is more, *bitbake* syntax is pretty complicated. In result, your life may become unbearable if the build configuration is too long. See next an alphabetical list of some important build configuration directives.

- BB_DISKMON_DIRS This *bitbake* variable enables free storage space verification. Users may add rules to monitor as many directories as they wish. Of course, it makes sense to add only directories on different storage partitions. The directive contains rules to trigger actions in case of low storage space during builds. Possible actions are *WARN*, *STOPTASKS* and *HALT*. Rules are defined in the following format.

```
"<action>,<directory path>,<space left>,<inodes left>"
```

- DISTRO This is the short name of the OS distribution. *Yocto* provides four variants of their reference distribution called *Poky*. See details in <META-DIR>`/poky/meta-poky/conf/distro/poky*.conf`. Some distribution dependent directive values are presented in Table 3.

- DISTRO_FEATURES Distributions can select which features they want to support through the DISTRO_FEATURES variable, which is set in the distribution configuration file.

- IMAGE_FEATURES This directive controls the contents of the OS *image*. Different predefined packages could be added, removed or modified via this variable. Useful examples for *image* features are `allow-empty-password`, `allow-root-login`, `empty-root-` `post-install-logging`, `splash`, `package-management` and `ssh-serve`

- IMAGE_FSTYPES This is another important directive. Here I have removed archived *images* to decrease the built time and added the *wic* format. One may want to use the *wic* command-line tool to list the partitions on a *wic image*. See how to copy *wic* to an *SD* card in Section 5.

- IMAGE_OVERHEAD_FACTOR This defines the free storage space on the `root` partition. Overhead factor of 2 means that the free space will be equal to the space already used by the OS. This will double the size of the image. The default value of 1.3 increases *image* size with 30 %.

- INHERIT This is a list of included *bitbake* classes. See Section 3.2.

- INIT_MANAGER The OS *init* process could be `sysvinit`, `systemd` or `mdev-busybox`.

- MACHINE No doubt, this is the most important directive, set here to *raspberrypi*4-64. You may want to change this value if you build an OS for a different HW. If you want to emulate *Raspberry* π on your host machine with *qemu*, set $MACHINE$ to *qemuarm*64. I confirm that this works although I did not find this approach very useful to test a GUI.

- MACHINE_FEATURES This directive controls machine features. It is set in the machine configuration file and specifies the hardware features for a given machine.

- PACKAGE_CLASSES There are different package formats used in various Linux-based OS's to distribute and manage programs. Both *Debian* package format - *deb* and *rpm* from *RedHat* do well, but recently I had issues with *ipk* so I disabled it.

- PACKAGE_INSTALL This is where to specify additional SW packages. This is useful for packages not included in the *image* by default. In my experience, the default OS has all necessary programs or compact alternatives. However this is the directive used to append *imgui*.

- SANITY_TESTED_DISTROS This is a list of tested *GNU is not UNIX* (GNU)/Linux distributions. Using another distribution is not prohibited, but a warning messages is generated each time *bitbake* is run. One may want to append the host machine Linux distribution to get rid of this warning. See next examples for users of rolling releases from *Manjaro* and *OpenSuse*.

```
SANITY_TESTED_DISTROS:append = " manjaro"
SANITY_TESTED_DISTROS:append = " tumbleweed-*"
```

- TCLIBC The GNU standard C library variant to use during the build. Available options are `glibc`, `musl`, `newlib` and `baremetal`.

config file	INIT_MANAGER	TCLIBC	status
`poky.conf`	`sysvinit`	`glibc`	fine
`poky-bleeding.conf`	`sysvinit`	`glibc`	unknown
`poky-altcfg.conf`	`systemd`	`glibc`	unknown
`poky-tiny.conf`	`mdev-busybox`	`musl`	unknown

Table 3: reference distribution configurations

3.2 classes

Find *bitbake* classes in <META-DIR>`/poky/meta/classes`. For example `rm_work.bbclass` defines a specific task for packages to remove intermediate files generated during the build. This decreases storage space about twice. Those who want to keep the working data and have enough storage space may comment the next line in `local.conf`.

```
INHERIT:append = " rm_work"
```

4 build

It is very likely that you will need to install *Yocto* requirements[9] to be able to run *bitbake*. The list of *Yocto* sanity checked distributions currently includes *poky*-3.3, *poky*-3.4, *Ubuntu*-18.04, *Ubuntu*-20.04, *Ubuntu*-22.04, *Fedora*-37, $Debian - 11$, *OpenSUSEleap*-15.3 and *AlmaLinux*-8.8. However, I do builds on *Manjaro* - a not officially supported GNU/Linux distribution - and it works fine.

4.1 requirements

Ensure that the following packages are installed.

- *git*
- *tar*
- *python*
- *gcc*
- GNU *make*

Find more details in *Yocto* documentation at [9]. You may need to install in addition `diffstat`, `unzip`, `texinfo`, `chrpath`, `wget`, `xterm`, `sdl`, `rpcsvc-proto`, `socat`, `cpio`, `lz4`, `gawk`, `findutils`, `crypt`, `mtools` and `inetutils`. As a double check, make sure to have the following command-line tools on your host machine: `chrpath`, `diffstat`, `lz4c`, `rpcgen`, `bash`, `bzip2`, `file`, `grep`, `patch`, `sed` and `mdir`.

The complete list of packages to install on Manjaro includes `git`, `tar`, `python`, `gcc`, `make`, `chrpath`, `cpio`, `diffstat`, `patch`, `rpcsvc-proto`.

Fetched *metadata* requires only 412 MB of free space. In contrast the OS build may need up to 30 GB or even 50 GB if intermediate files are kept. Read about the *bitbake* class *rm_work* in Section 3.

4.2 environment

The primary build tool of *OpenEmbedded* based projects, such as *Yocto* is *bitbake*. To initialise *bitbake* build environment navigate to <META-DIR>`/poky` and source the initialization script like the next command.

```
source oe-init-build-env <BUILD-DIR>
```

The script changes the system path to <BUILD-DIR>. Next, you may want to run the following command to check project layers.

```
bitbake-layers show-layers
```

Alternatively, source the dedicated *portable operating system interface* (POSIX) script <META-DIR>`/thc/meta-thc/bin/yoctoinit`. First of all, uncomment the two lines in the script to define the system path to <META-DIR> and <BUILD-DIR>. In addition to the environment initialisation, the script defines some useful functions. Have a look at the code for details.

The target `core-image-thc` is a compact OS image with a *X* server and a running GUI[2] example. Run next command to build the OS.

```
bitbake core-image-thc
```

Unless your host machine is a supercomputer, this will take at least two hours. Find a list of tasks performed by *bitbake* for a typical SW package in Table 4. If a build is interrupted during a fetch task, this could be the connection with a server. A simple rerun of *bitbake* may solve this issue. If not, you may try rebuild the target responsible for the failure. See next how to do this.

task	description
do_fetch	fetch the source code
do_unpack	unpack the source code
do_patch	apply patches to the source
do_configure	source configuration
do_compile	compile the source code
do_install	copy files to the holding area
do_populate_sysroot	copy files to the staging area
do_package	analyse holding area
do_package_qa	check quality
do_package_write_rpm	deploy SW package in *rpm* format
do_package_qa	quality checks on the package

Table 4: *bitbake* tasks

```
bitbake <target> -c clean && bitbake <target>
```

4.3 flow

The build happens in <BUILD-DIR>. Table 5 presents a list of important <BUILD-DIR> sub-directories.

Source archives are saved in the *download* directory. They are extracted, configured, compiled and installed in the *work* directory. Built packages are stored in the *package* directory. Finally, following the build configuration packages are unpacked to create the OS *image* found in the *image* directory. The build flow is summarised in Table 5.

name	location	description
configuration	`conf`	build configuration files
download	`downloads`	fetched SW source code archives
work	`tmp/work`	working directory
package	`tmp/deploy/rpm`	final SW packages in *rpm* format
image	`tmp/deploy/images`	boot files, kernels and *images*

Table 5: *bitbake* workflow

5 install

The OS includes a kernel *ARM*, 64 bit boot executable *image* of 23 MB, a *Raspberry* π configuration of Linux 5.15. This is a $long-term\ support$ (LTS) kernel release. The total size of kernel modules is 21 MB.

Yocto provides multiple package and *image* formats. Different ways exist to install *images* on *SD* card. The OS has two partitions - `/root` and `/boot`. There are no *swap* and *home* partitions.

I recommend the classic command-line tool *dd* to copy data. It works fine with different *image* formats like $rpi-sdimg$, *hddimg* and *wic*. The last one is recommended. Find the *SD* card device name, for example `/dev/<xxx>`, unmount it with *umount* if mounted, and do copy data with the next command.

```
dd if=core-image-thc-raspberrypi4-64.wic of=/dev/<xxx> status=progress
```

- note 1: run this command in <BUILD-DIR>`/tmp/deploy/images/raspberrypi4-64`
- note 2: run this command with *root* privileges
- note 3: be careful to not specify the device name of your hard drive (see note 2)

Alternatively, there is a dedicated POSIX shell script - <META-DIR>`/thc/meta-thc/bin/burn`. Use the command-line option `-h` for details. The transfer does not take long. When it is over, replace the card to *Raspberry* π and turn it on. That's it.

6 run

Wireless connection is established via classic command-line tools like `ip`[1] and `iw`. The *dynamic host configuration protocol* (DHCP) client is `udhcpc`[1], and `wpa_passphrase`[7] stores WiFi connections. A dedicated POSIX shell script named `wifini.sh` is installed in `/usr/bin`, as well as a running GUI example to demonstrate the usage of the *Dear ImGui*[2] library. The last one is configured to start automatically on boot in `/home/root/.profile`.

```
#!/bin/sh
# name:    wifini.sh
# purpose: wifi connection
# code:    kaloyansen at gmail dot com
# require: wpa_passphrase, wpa_supplicant, ip, iw, grep, awk
#########################

# files
MYNAME=`basename $0`
WPACONF=/etc/wpa_supplicant.conf
IFCONF=/etc/network/interfaces

# command-line tools
WPAPASS=/usr/bin/wpa_passphrase
IW=/usr/sbin/iw
WPASUPP=/usr/sbin/wpa_supplicant
DHCP=/sbin/udhcpc
IP=/sbin/ip

die() { echo $MYNAME $* && exit 0; }
say() { echo $MYNAME $*; }
auto() { # enable wifi connection on boot
    patch=auto\ $WIFACE
    say $patch
    grep "$patch" $1 > /dev/null || printf "
$patch
# wpa-roam $WPACONF

" >> $1;
}

[ "$USER" == "root" ] || die run with root privileges

# get wifi interface and network ssid
IWD=`$IW dev`
WIFACE=`echo $IWD | grep Interface | awk '{print $3}'`
SSID=`getopt s: $* | awk '{print $2}'`

say whoami: $0

[ $SSID ] && say network: $SSID || die specify network: $MYNAME -s SSID
[ $WIFACE ] && say interface: $WIFACE || die wireless interface not found
```

```
# verify connexion
echo $IWD | grep $SSID > /dev/null && die $SSID connected || say connecting $SSID

# up interface
$IP link show $WIFACE | grep UP > /dev/null || $IP link set $WIFACE up

# search network
$IW $WIFACE scan | grep $SSID > /dev/null || die cannot find $SSID

FINE=`grep $SSID $WPACONF`

# die debug $FINE

# 1. save network in $WPACONF
[ $FINE ] && say $SSID already configured || $WPAPASS $SSID >> $WPACONF

# 2. configure wifi to start on boot in $IFCONF
[ -f $IFCONF ] && auto $IFCONF || die $IFCONF not found

# 3. reboot
say reboot in six seconds   && sleep 3
say reboot in three seconds && sleep 2
say reboot in one second    && sleep 1
# yeah no kidding
reboot & die see you later || kill $$

# control files
WPASOCKET=/run/wpa_supplicant/$WIFACE

# process id files
WPAPID=/run/wpa_supplicant.$WIFACE.pid
DHCPID=/run/udhcpc.$WIFACE.pid

# recreate wpa socket
rm $WPASOCKET
$WPASUPP -B -D wext -i $WIFACE -c $WPACONF || say cannot create $WPASOCKET

# start a dhcp client
$DHCP -i $WIFACE || die $?

$IP addr show $WIFACE
$IW $WIFACE link
$IP route show
```

The scrip may be downloaded here but it is already installed on the target OS. Specify network *id* from the command line with a short command-line option s. See next example usage.

```
wifini.sh -s <SSID>
```

The script asks for the network password to store it encrypted for future connections. Once an *internet protocol* (IP) address is assigned to *Raspberry* π network device, the SSH server by *Dropbear*[4] allows for secure remote login, control and file transfer.

7 outlook

This reports the progress in the development of a custom Linux-based OS for *Raspberry* π[6]. The kernel version of this embedded OS is Linux release 5.15. An example GUI application using the *Dear ImGui* library is built as a part of the OS *image*. In addition, an SSH server provides remote connection, data transfer and device control.

As the OS is now functional, performance and real-time tests are ongoing. For precision measurements the OS has to be tested both on the target platform and on virtual HW via emulators, e.g. *quick emulator* (QEMU) <META-DIR>`/poky/scripts/runqemu`.

acronyms

BSP	*board support package*
CLI	*command-line interface*
DHCP	*dynamic host configuration protocol*
GNU	*GNU is not UNIX*
GUI	*graphical user interface*
HW	*hardware*
IP	*internet protocol*
LTS	*long – term support*
OS	*operating system*
POSIX	*portable operating system interface*
QEMU	*quick emulator*
SSH	*secure shell*
SW	*software*

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(visited on 2023).

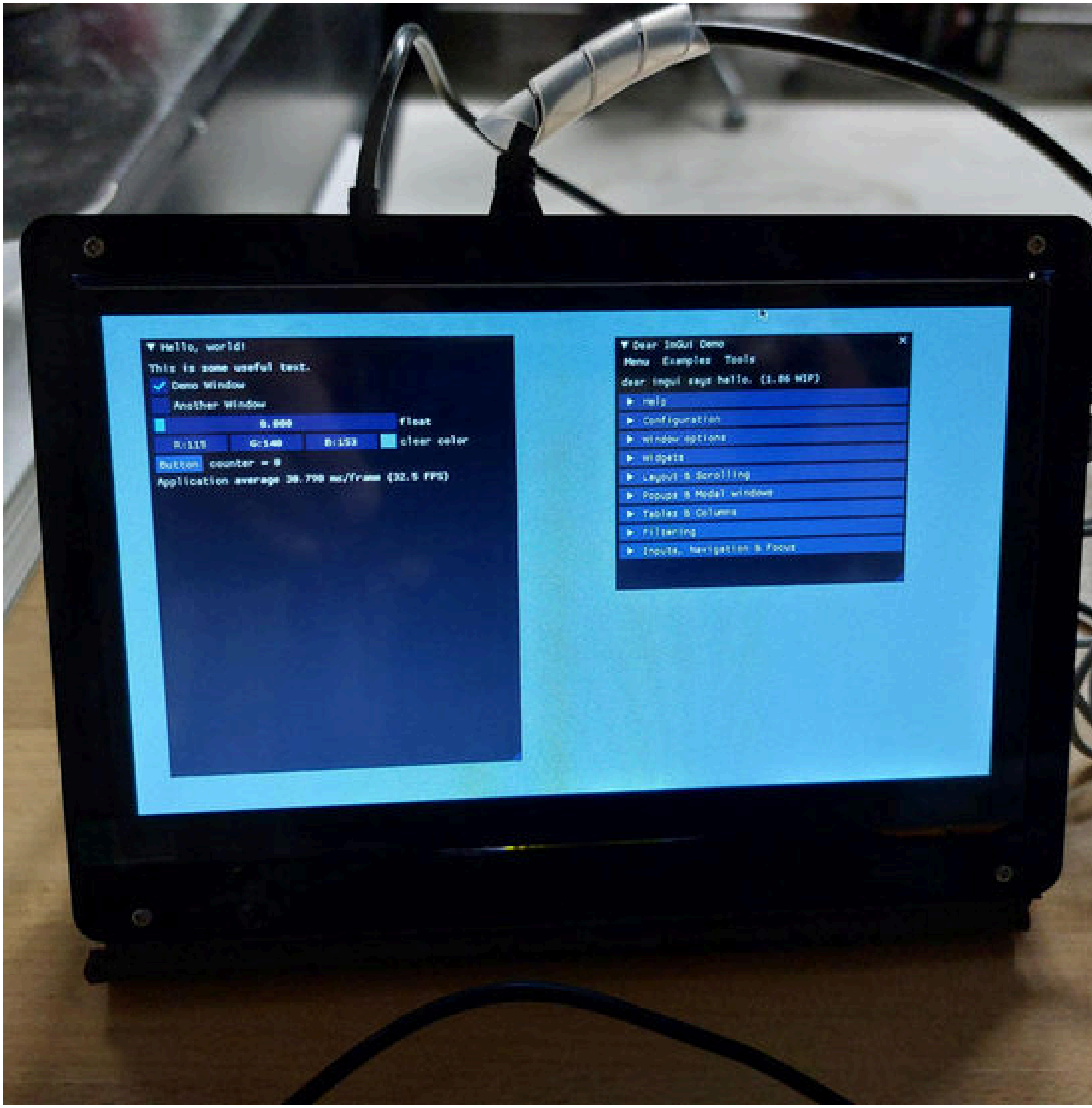

Figure 1: *Raspberry* π - 4 - *model B* behind a Kuman Capacitive 7" touchscreen TFT LCD module